10/018817
JCO[illegible]c'd PCT/PTC 17 DEC 2001

42637/GDL/N288

METHOD APPARATUS AND ARTICLE OF MANUFACTURE FOR BRANDING A DIAMOND WITH A FOCUSED ION BEAM

BACKGROUND

I. FIELD OF THE INVENTION

The present invention relates generally to the field of the handling of precious gems and more specifically to the branding of a design onto a precious gem such as a diamond.

II RELATED ART

In the handling, marketing and sale of precious stones, such as diamonds, as well as the sale of jewelry made from these precious stones, it is common practice for jewelers and diamond merchants to grade precious stones to determine their value based on such features as cut, weight, color and the purity of the crystalline structure of the stone. These attributes contribute to much of the value of an individual stone. Conventionally, these attributes are recorded on paper or other media separate from the stone itself. These attributes and the documents which record these attributes typically become a means of both determining the value of the stone and properly identifying its owner. Thus, because this information is so important, this information must be accurately and reliably conveyed to the

purchaser of the stone during a sale or other transfer of ownership.

It is equally important to the owner of a particular piece of jewelry containing precious stones to be able to accurately identify the piece of jewelry and the individual stone or stones set in that piece of jewelry. Although most luxury and consumer goods carry serial numbers or other indications of ownership, so that owners can verify their ownership of goods of similar appearances, differentiate between genuine goods and counterfeit goods at purchase,

and have an indication of ownership for insurance purposes, this is, for the most part, not the case with precious stones. Although some stones are marked with the use of lasers, the vast majority of stones on the market today are unmarked. Currently, most consumers must rely on the representations of the jeweler who sells, cleans or works on the piece of jewelry that it is in fact authentic.

In addition to and concurrent with the security reasons which would make indelibly marking stones beneficial, the ability to indelibly mark stones would also be helpful for inventory control purposes. Specifically, both wholesalers and retailers of diamonds and other precious stones have no method of placing inventory control markings, such as bar codes indelibly upon stones.

In addition to these reasons for indelibly marking stones, purchasers of stones frequently seek to personalize the stones or the jewelry in which they are set. Desired personalizations include messages, marriage certificates, and poems, as well as symbols and images.

Presently, accurate identification of precious stones for transmittal of attribute information or identification purposes is difficult because no commercially viable method for indelibly marking stones without defacing them and affecting their value is available. To preserve the value of the stone and still create an indelible marking on the stone, any marking or information placed on the stone must be extremely small, such that it is invisible to the naked eye, and preferably, to a 10X magnification power, which is the typical magnification power of a jeweler's loupe. However, it is apparent that the marking must be able to be detected in some manner for it to be of use.

Also, to ensure that markings are visible when a stone is mounted in a jewelry setting, any commercially successful marking system must be able to mark a stone on its "table," i.e. the large exposed top surface of the gemstone, rather than on the "girdle" or edge of the stone. This is because the girdle, or sections of the girdle, are frequently obscured or placed beyond view when a stone is set in a piece of jewelry. Additionally, because the girdle of the stone is a relative exposed portion of the stone, *i.e.*, it is frequently where a stone is grasped when handled, it

is very easy to scratch off or damage any markings made on the girdle of the stone. Also, an ideally cut stone has very little flat surface at the girdle, but instead has a sharp edge. If a marking is to be made on the girdle of the stone, it is sometimes necessary to cut the stone in less than an ideal cut, so that a flat surface at the girdle of the stone can be created.

Examples of prior art systems which attempted to solve the problems of indelibly marking precious stones include U.S. Patent No. 4,392,476 to Gresser, et al., which describes the use of laser energy directed at the stone to inscribe the girdle of the stone with a desired marking; U.S. Patent No. 4,467,172 to Ehrenwald et al., which describes a laser system for inscribing permanent identification markings on or below the surface of the girdle of a diamond; and U.S. Patent No. 5,149,938 to Winston, et al., which describes a method of marking a diamond on its girdle by irradiation with an argon fluorine excismer laser whose output beam is passed through a mask which defines the marking.

One feature of each of these devices is their reliance on lasers. The use of a laser to cut or mark a diamond or other precious stone results in the disadvantages of the creation of microscopic cracks in the diamond as well as a "white-frosting" effect or a "dark-regions" effect which degrade the clarity of the diamond. These effects are especially pronounced when lasers are used to mark or brand the table of a diamond, rather than the girdle of a diamond. A still further disadvantage is that the

beams of most lasers are relatively wide and thus create large branding marks, i.e. large pixels as shown in Gresser, Fig. 3. This in turn limits the precision with which a marking can be made. Lasers also have limited ability to create "grey-scale" images which depend on contrast between adjacent "pixels." It will be understood that " grey-scale" images are created by varying the depth of the brand or pit which is cut into the surface of the diamond at a given pixel. Because it is very difficult to control the depth of a cut made by a laser, accurate and reliable "grey-scale" images are difficult to produce with lasers.

Accordingly, there is a need in the art for a method of indelibly marking a diamond or precious stone without damaging the clarity of the stone. Further, there is a need for these indelible markings to be of high resolution and for an indelible marking method to be capable of producing "grey-scale" images. The present invention includes these features, as well as other features and advantages as are described below.

SUMMARY OF THE PREFERRED EMBODIMENTS

In a preferred embodiment, a diamond is branded by first securing the diamond onto a holder capable of being used in a coordinate transfer system. Next, a coordinate transfer system is used to create a set of mapping data which represents the distances between the location on the diamond which will be

branded and certain set reference points on the holder. At the same time, a computer is used to convert a design to be branded on the diamond into design data capable of being processed and used by a focused ion beam machine. The mapping data is then used in conjunction with the design data to control the focused ion beam machine such that it produces a focused ion beam which impacts the diamond at a desired location for a desired length of time to brand the design onto the diamond.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 a perspective view of a diamond which has been cut and polished as a round brilliant cut.

FIG. 2 is a magnified, planar view of the portion of FIG. 1 enclosed by Circle 2.

FIG. 3 is a flow chart illustrating the order of operation of the method of the present invention.

FIG. 4 shows a perspective view of a holder for diamonds in accordance with the present invention.

FIG. 5 illustrates an inverted, cross-sectional view of the holder of FIG. 4 along the line 5-5.

FIG. 6 schematically illustrates the positions of the diamonds and the reference points on a holder of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In a preferred embodiment of the present invention, a diamond, such as the one illustrated in FIG. 1, is indelibly marked with a design by a focused ion beam machine. It will be understood that this invention can be used for the marking of other types of precious and semi-precious stones and that although the description which follows refers, by way of example, to the marking of diamonds, this description is not to be taken as limiting. With reference to FIG.1, a diamond 100 which has been cut and polished as a round brilliant has a table 102, which is the top-most surface of a diamond when it is placed in a setting such as a ring. For the particular cut of diamond shown, the table 102 is in the shape of an octagon. The diamond is visually separated into two portions, known as the crown 104, which is the upper portion of the diamond, and the pavilion 106, which is the lower portion of the diamond. The crown and pavilion are separated by a girdle 108. The diamond also has a number of different facets 110 which serve to give the diamond its unique shape, its light refracting properties, and which naturally define edges 112 between facets.

A portion of the table 102 encircled by Circle 2 is shown magnified in FIG. 2. With reference to FIG. 2, the edges 200 correspond to the edges 112 between the table 102 and several facets of FIG. 1. A design 202 is branded into the surface of the table 102. It will be understood by one of ordinary skill in the

art that, based on the explanation below, the design could consist of images, bar codes, numbers or letters which are necessary to identify the stone, describe its attributes, mark the stone with a trademark of the manufacturer, engrave a personal inscription, mark the stone with a family crest, a copy of a photograph or whatever other marking might be desired by the user or purchaser.

It is preferred that the branded design is located on the table of the diamond. This allows the brand to be observable by a microscope even when the diamond is placed in a jewelry mount or setting such as a ring. If the brand is located on the girdle or the pavilion, it can be obscured by a prong of a setting when the diamond is placed in a ring, thus frustrating the identification aspect of the present invention.

The design 202 is about two-hundred and fifty (250) micrometers wide, however the present invention is capable of producing a brand as small as seven (7) nanometers wide. At about 250 micrometers, the design is small enough that it will not be visible to the naked human eye, and will be difficult to detect with a jeweler's loupe, but will be visible with a an optical microscope with a magnification of 100X. This is the result of the shallow depth of the brand, which is preferably no more than 20-40 nm. Alternatively, it is possible to produce a brand of greater depth (such as, for example as deep as 120 nm) with the concurrent advantage of providing greater resolution for grey-

scale images, however, deeper brands may be visible to a jeweler's loupe under certain circumstances.

In a preferred embodiment, the design 202 is composed of graphite bonded to the surface of the diamond and included beneath the surface of the diamond. This embodiment allows the design to be effectively viewed by an infra-red microscope in addition to an optical microscope, because graphite is a good conductor of electricity, while diamond is not a good electrical conductor. As a result, when viewed by an infra-red microscope, design 202 will appear as a bright white image, while the surrounding diamond will be a dark grey color. Alternatively, this graphite can be removed, as described below, leaving a design in the form of a carving of varying depths in the surface of the diamond.

With reference to FIG. 3., processing begins by selecting the diamonds to be branded 300 and then cleaning them 302 before branding. It will be understood that the cleaning process can be accomplished by any acceptable process for cleaning diamonds such as immersion in an ultrasonic bath of isopropyl alcohol. Next, the diamonds must be secured to a holder which is capable of being used in a coordinate transfer system 304.

An example of one such holder 400 is shown in FIG. 4 and includes a base 402 which is composed of an electrically conductive material such as copper or aluminum. At regular intervals, holes 404 have been formed through the base 402 of the holder which generally correspond in circumference to the

circumference of a cut diamond. With reference to FIG's. 4 and 5, the holder 500 has a plurality of holes 502 drilled through from the top side 504 to the bottom side 506 each hole 502 is approximately the same circumference as the circumference of a diamond to be mounted in the holder. To mount the diamonds, the holder is placed upside down, as shown in FIG. 5 so that the top side 504 is in contact with a silicon wafer 507, or some other suitable extremely level and uniform surface. One diamond 508 is inserted into each hole 502 such that its table is in contact with the silicon wafer or level surface. Once all of the diamonds to be mounted are placed in the holder, a plug 510 is inserted into the hole 502 to secure the diamond. Each plug has a small depression 512 carved in its top 514 which conforms roughly to the shape of the pavilion 516 of the diamond 508 to be mounted. Each plug is composed of a conductive material such as copper or aluminum. Each plug is secured to a diamond and the holder itself by a suitable amount of electrically conductive paste 518 or other material capable of creating a conductive bond. Preferably, the paste is composed of graphite and 2-propanol and when dry bonds the diamond to the topside of the plug 514 and also bonds the top of the plug 514 to the holder 500. Enough adhesive should be used to secure the diamond to the holder 400 so that it will not move while the holder is being handled and processed by both the coordinate transfer system and the focused ion beam machine.

It will also be understood by one of ordinary skill in the art that more than one diamond can be placed in the holder at a time, and that the number of diamonds which can be processed by the coordinate transfer system at a time is limited only by the size of the holder that the particular coordinate transfer system used will accept. It will be further understood that the holes 404 can be formed to accept various cuts of diamond and precious stone and that the present invention is not limited to the round brilliant cut which is illustrated. While it is preferable that the diamond be oriented so that it can be branded on its table, the present invention is capable of modification to allow branding on any surface of a diamond. The holder 400 also includes at least three reference points 408 which are used by the coordinate transfer system.

The diamond must also be coated with a thin conductive layer 306. Preferably this layer is no more than ten (10) nanometers thick. Because the surface of a diamond builds up a positive charge, in order for a positively charged focused ion beam to effectively impact the diamond, the surface of the diamond must be charged neutral. In a preferred embodiment, the diamond is coated with a thin coating of carbon particles. This may be accomplished by a carbon-coater such as the Cressington Scientific Instruments 108 Carbon, manufactured by Cressington Scientific Instruments. Alternatively, the conductive layer can be composed of any suitable conductive material such as, for example, gold,

platinum, or chromium. In another embodiment of the invention, a charge neutralizer (also called a "flood gun") can be used to neutralize the positive charge built up on the surface of the diamond prior to and during branding with a focused ion beam. It will be understood that the order of steps 304 and 306 can be reversed, *i.e.* that the diamond may first be carbon coated and then subsequently secured to a holder.

Next, the holder is inserted by an operator into the coordinate transfer system. An example of one such coordinate transfer system is the JMAR Mirage, which is manufactured by JMAR Precision Systems, Inc. of San Diego, California. The JMAR Mirage is an extremely accurate tabletop automatic measuring system with an X-Y-Z travel of 10" x 4" x 2". The JMAR Mirage includes high powered microscope objectives and can be used with or without a laser autofocus for high speed Z-axis measurement and on-the-fly focusing of a video image of the object being measured. Optionally, the JMAR Mirage may also include microscope optics using a two-position precision automatic lens shuttle.

The JMAR Mirage then develops accurate mapping data for the diamonds in that holder, as indicated in block 308. The holder 400 shown in FIG. 4 is shown schematically in FIG. 6. The holder 600 includes holes with diamonds secured in them 602. For purposes of explanation, the table portion of each diamond 602 is shown as an octagon. The holder also includes a first reference point 604, a second reference point 606 and a third reference

point 608. Preferably, each of the three reference points has a sharp distinguishable corner that can be easily identified by the video-imaging system of the JMAR Mirage. The three reference points are located at the outermost edges of the holder and are aligned with the rows of diamonds. Also preferably, the three reference points are each formed to a different predetermined depth into the base 402 of the holder, to allow for calibration of the "Z" axis by the JMAR Mirage.

The JMAR Mirage system identifies the first reference point 604 and uses it as a base point for an X-Y coordinate system. The JMAR Mirage system accurately identifies the first reference point by using its video imaging system to locate the reference point, identify the edges of the reference point, and then fix the relative position of this reference point in its memory. This same process is then performed to locate and fix the second reference point 606, and the third reference point 608. This measuring results in the creation of an X-Y coordinate axis based on the fixed locations of the reference points. For convenience, an X-Y axis 610 is indicated in the drawing. The JMAR Mirage then proceeds to impose this coordinate system on the holder and to measure how far each diamond is from the first reference point 604 and the second reference point 606; i.e. the horizontal and vertical offsets. The JMAR Mirage further determines the exact locations of every visible surface of the diamonds secured to the holder 600. The JMAR Mirage also uses first reference point 604

and second reference point 606 to determine a reference line 612. The reference line 612 is in general alignment with the rows of diamonds in the holder 600. Each diamond 602, however, will not be perfectly aligned with the reference lines 610. Specifically, one edge 614 of the octagon shape that forms the table of the diamond is generally parallel with the reference lines 610, but at the microscopic scale, the edge 614 of the table each diamond will be rotated slighted away from being perfectly parallel. The JMAR Mirage determines the angle by which the edge 614 of each diamond is out of parallel alignment with reference lines 610. Using the JMAR Mirage Imaging system to first locate a corner on a diamond, then focus on one edge of the diamond and then trigonometrically determine both the branding point and the angle between the edge of the diamond and the reference line. This angle indicates how far the diamond is out of alignment from the reference line and allows the JMAR Mirage to determine a rotation value. This rotational offset data will subsequently allow the focused ion beam machine to brand each diamond such that the design on each diamond is correctly positioned with reference to an edge 614 and so that design is "lined-up."

The JMAR Mirage is controlled by a computer to accomplish the functions described above. It will be understood by one of ordinary skill in the art that these functions are preferably programmed in autoTHP, but could be implemented in other programming languages. Similarly, minor modifications and

variations can be made to the code without departing from the scope of the present invention.

After these functions are carried out, a set of mapping data which consists of an X-Y-Z coordinate system mapping the locations of the diamonds, as well as rotational data, has been developed. This mapping data is then transmitted to the focused ion beam machine, as shown in FIG 3, block 310.

While the diamonds are being processed as described above, the design to be branded onto them must also be processed. This begins when the operator determines the design to be applied to a diamond, or if multiple diamonds are placed in a holder, when the operator determines which design will be applied to each diamond 312. Next, the design is input into a computer by optical scanner, or electronic means such as a file transfer from a storage medium. The computer then converts the design into stream files which create a local coordinate system for the design, and then assigns X_1-Y_1-dt values to this coordinate system representing the design as shown in block 314.

After these functions are carried out, a set of design data has been developed. This design data is then transmitted to the focused ion beam machine, as shown in FIG 3, block 316.

It will be understood that the X_1 and Y_1 values will be mapped to and, when the design is branded on the diamond, these values will be integrated into the X-Y coordinate system in the mapping data. The dt data is the darkness or contrast of each

individual pixel shown in the design. When the design is branded onto the diamond, the depth of the brand will be varied by varying the amount of the time in which the ion beam strikes the surface of the diamond. This in turn varies the relative darkness of that pixel of the brand.

It will be understood that this process can be done before, after, or simultaneously with the process of selecting and measuring the diamonds. However, for maximum efficiency and output from the process, it is preferred that the selection and conversion of the design be done simultaneously with the selecting and measuring of the diamonds to be branded.

Next, a computer controlling the focused ion beam machine receives both the mapping data and the design data. The focused ion beam machine itself is preferably a Gallium ion based machine. However, any liquid metal or gas based focused ion beam machine would be acceptable. An example of one such machine which is suitable for the process disclosed is the FIB 200 THP, manufactured by FEI Company of Hillsboro, Oregon. The computer maps the local coordinate system of the design to be branded, which is a part of the design data, onto the global coordinate system which is contained within the mapping data. The computer then uses this merged data to control the focused ion beam machine to accurately direct the focused ion beam so that it strikes the surface of the diamond to be branded at a particular location for a particular amount of time such that the surface particles of the

diamond which are impacted by the ion beam are converted into graphite.

After these functions are carried out, the diamond or diamonds in the holder are branded and the design is formed in graphite set into the surface of the diamond.

Optionally, this graphite can be removed as shown in block 320. This can be accomplished by a number of different methods, but is preferably done by exposure to potassium nitrate (KNO_3) at 500°C for approximately forty minutes in a ceramic crucible. Alternately, the carbon can be removed by exposing the diamond to an oxygen plasma. As one of ordinary skill in the art will appreciate, the diamond to be cleaned is placed in the vacuum chamber of a plasma cleaning system, such as the Plasmod, manufactured by March Instruments of Concord, California. A gas, typically oxygen, is introduced into the chamber and electrically charged to create a reactive plasma. The plasma reacts with the graphite and removes it, while leaving the diamond untouched. The by-products of this reaction are then removed by a vacuum pump. Finally, removal of the graphite can also be accomplished by immersion in an acid bath.

CONCLUSION

The foregoing description of the preferred embodiment of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the

invention to the precise form disclosed. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto.